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WATER SUPPLY IMPLICATIONS AND METHODS
OF REMOVAL

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Radioactive materials found in surface waters generally arise from four sources: fallout, naturally occurring radionuclides, man-made radionuclides released to water during normal and routine operations of nuclear energy facilities, and the spent residues from the use of specific radionuclides for beneficial purposes. At the present time, with few exceptions, the bulk of the radioactivity found in surface waters has its origin in fallout ^{and natural radioactive material} / The amount of activity contributed from fallout varies and is dependent upon geographical position, climatological conditions, and frequency of weapons tests.

Gross Activity Levels from Fallout

Straub, et al. (1), estimated the contribution of fallout in the form of gross beta activity over the entire U. S. area and compared this with gross beta activity contained in runoff. The contribution from fallout was calculated from rainfall data released by the National Radiation Surveillance Network (2) and the runoff from data available from the National Water Quality Network (3). These estimates showed

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that over the entire United States, with an average gross activity level in rainfall of 1470 $\mu\text{C}/\text{liter}$ (2), the daily contribution of fallout amounted to 23,900 curies of gross beta activity. Runoff amounted to 408 curies daily. Certain areas, as for example, the Ohio River basin, showed somewhat higher deposition rates namely 45,300 curies/day, but this would be expected because of greater rainfall rates and other climatological factors. Analyses of the data (4) covering operations of the first year of the National Water Quality Network by Setter, Regnier, and Diephaus (5) showed quite marked variations in surface water activity levels for the different stream drainage basins.

Gross Activity from Other Sources

In Table I are summarized the estimated quantities of water and gross activity discharged from other sources. *It must be remembered that these are gross data & the hazard associated with each is dependent on the nuclide composition.*

Strontium-90 from Fallout

Straub, et al. (1), also estimated strontium-90 deposition and runoff over the U. S. These estimates were based on strontium activity levels in precipitation reported by the U. S. Atomic Energy Commission (7,8) and the strontium-90 levels found in surface waters. They (1) found that the strontium-90 contributed by precipitation averaged 236 curies/day and that in runoff amounted to 6.4 curies/day during the first quarter of 1959. Similar calculations for the Ohio

Table I. Estimated Quantities of Water and Activity Discharged
(United States Practice)

Source	Volume Discharged M^3/day	Activity Discharged curies/day	Reference
Mills	6.8×10^4	- 100	(6)
Feed Materials Plants	0.1×10^4		(6)
Reactor Coolant	8.0×10^4 (a)	- 410 ^(a)	(6)
Isotope Users	$1.1-1.9 \times 10^4$ (b)	1 - 2	(6)

(a) Average since 1944 at Hanford.

(b) Based on assumption that isotopes used have an MPC value of 10^{-4} $\mu c/ml$ and that they are reduced to the MPC level before release.

River Valley based on activity values at Cairo, Illinois, yielded values of 15.6 and 1.0 curies/day for strontium-90 deposition and runoff, respectively, during the first quarter of 1959. From these data it is possible to estimate the degree of holdup of strontium-90 and gross activity by natural agents. This activity may find its way into the water course at some later time during periods of high runoff when soil erosion is quite marked or during resuspension from soil or organic matter.

Generally speaking, activity levels should be somewhat lower in streams than in reservoirs, lakes, or impoundments. In the former case, with a dynamic system such as the river, the activity added today will have moved to a new location tomorrow, the distance of movement being a function of the hydraulics of the stream system and the removal and temporary holdup of the radioactive materials in the associated biota and bottom muds. In the case of lakes, reservoirs, and impoundments, however, all of the activity entering the system is retained within the confines of the system, and the ratio of the longer-lived radionuclides to the total activity increases with time.

Strontium-90 Levels in Cisterns

A third source of water must also be considered and that is cistern water. Notwithstanding their primitive design, cisterns are used as sources of water supply in many fringe suburban areas as well

as in rural locations, particularly where other sources of water are not available. Analyses have been made of cistern waters in a single facility in the Cincinnati area for some time and the strontium-90 levels found are summarized in Table II.

Significance of Radioactivity Levels

Now that we have some data on levels of radioactivity found, what is the significance of these levels? There will be a wide variation in levels due to local conditions of rainfall, runoff, geology, hydrology, etc. Furthermore, before the significance of any given levels of activity can be determined, the make-up of the activity observed must be known. This is particularly true, since there seems to be no direct ratio between the gross beta activity levels and the strontium-90 levels as indicated by the scatter diagram shown in Figure 1.

Radionuclide analyses must be made to identify the more hazardous radionuclides. Because of its long biological half-life and deposition in bone, the most hazardous man-made radionuclide is strontium-90. Of the naturally occurring radionuclides, radium is the most hazardous and is encountered in some ground water supplies at significant levels. The maximum permissible occupational body burden established by the ICRP (9) and NCRP (10) for strontium-90 and radium-226 are 2 μ c and 0.1 μ c, respectively. From these values maximum permissible

Table II. Strontium-90 Activity Levels in Cistern Waters

Type	Date	No. Obs.	Activity - $\mu\text{pc/l}$		
			Mean	Median	Range
Coast Guard	1958-4th Quar.	2	4.0	4.0	2.76- 5.17
	1959-1st Quar.	12	3.7	3.7	0.9 - 7.3
	1959-2nd Quar.	10	3.2	3.0	0.2 - 8.5
	1959-3rd Quar.	9	1.1	0.4	0.2 - 3.5
Local-Civilian	1959-January	7	4.9	4.9	3.4 - 6.0
	1959-February	8	6.4	5.5	3.5 -14.6
	1959-Apr.-June		11.3		
	1959-July-Sept.		1.0		
	1959-October		5.9		

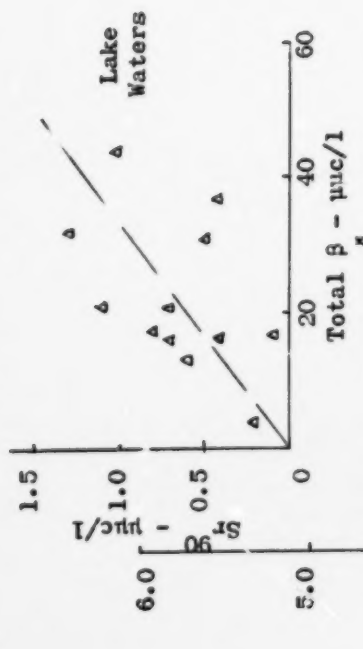
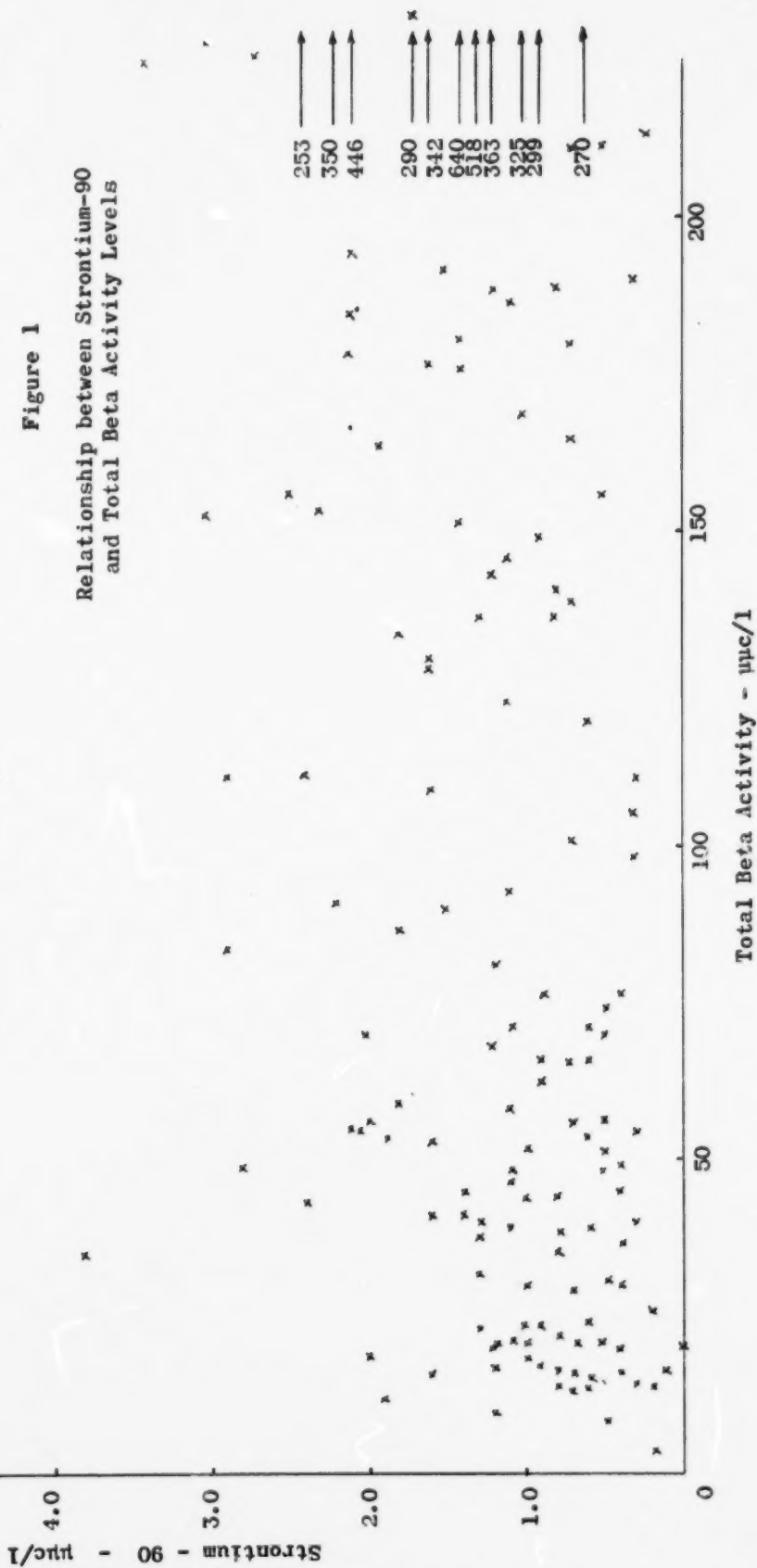


Figure 1
Relationship between Strontium-90
and Total Beta Activity Levels



Total Beta Activity - $\mu\text{c/l}$

concentrations (MPC) values in water and air have been established.

The 168 hour week MPC for these nuclides in drinking water is 1,000 and 100 respectively.

$\mu\text{pc/liter}$,/ Both the NCRP and ICRP suggest reducing these maximum levels by a factor of 10 for the so-called controlled area. The ICRP has also suggested an average permissible concentration for the general population at a factor of 3 below the maximum controlled area concentration. Applying both factors to strontium-90 would reduce the average permissible concentration to the general public to 33 $\mu\text{pc/liter}$ for drinking water.

This level of 33 $\mu\text{pc/liter}$ represents strontium-90 from all sources, i.e., water, air, diet, etc., where this is the only radionuclide contributing to the exposure of the population. Where populations are receiving radiation exposure from other sources, this average level of 33 $\mu\text{pc/liter}$ would have to be reduced, *to be consistent with the system of calculation used* Perhaps the *significance of current strontium-90 levels could be best illustrated* *in the recommendations.* by considering several examples.

Environmental Levels of Strontium-90

Total strontium levels in rains at Cincinnati have been as high as 1045 $\mu\text{pc/liter}$ for an individual rain. The strontium-90 content at this level would be estimated at about 30 $\mu\text{pc/liter}$. The rainfall strontium-90 level across the country amounted to about 5.3 $\mu\text{pc/liter}$ during 1958. The cistern levels found in Cincinnati range from 1.0 to

14.6 $\mu\text{c}/\text{liter}$. The levels in the streams across the country have shown median concentration levels of 0.9, 1.4, and 0.7 during the first three quarters of 1959. Thus, it can be seen that there is an appreciable removal of strontium-90 between its arrival on earth as fallout and its presence in the stream as runoff.

Using the intake value of 2.2 liters of water per day, this means that the average permissible intake of strontium-90 as the sole source of irradiation amounts to $2.2 \times 33 = 72.6 \mu\text{c}/\text{day}$. A cistern level of 14.6 $\mu\text{c}/\text{l}$ represents an intake of 32.1 $\mu\text{c}/\text{day}$ or approximately 44 per cent of the average permissible intake. In the case of surface waters with intakes based on the median concentration values given above, the daily intake amounts to 2.0, 3.1, and 1.5 μc or approximately 6.0, 9.4, and 4.5 per cent, respectively, of the average permissible intake of 72.6 $\mu\text{c}/\text{day}$.

The strontium-90 levels reported in the streams will be lowered somewhat by water treatment facilities. The degree of removal will be a function of the type of process employed as will be indicated later.

In Table III the sources contributing strontium-90 to man are shown along with the amounts of strontium-90 ingested daily. Similar calculations for other radionuclides of interest will permit determination of radiation exposure levels from all sources and will indicate the seriousness of such exposure. From Table III, it is seen that the bulk of the strontium-90 ingested is through the dietary route, with

Table III. Strontium-90 Contamination - Environmental Sources - Cincinnati, Ohio Data

Source	Level of Sr-90 $\mu\text{c/l}$, $\mu\text{c/M}^3$ $\mu\text{c/kg}$	Daily Intake ml or gm	Intake of Sr ⁹⁰ $\mu\text{c/day}$
Air	0.04 $\mu\text{c/M}^3$	2×10^7 ml	0.8
Water			
Cistern	0.3 - 20 $\mu\text{c/l}$	2200 ml	0.7 - 44
Surface	0.6 - 0.9 $\mu\text{c/l}$	2200 ml	1.3 - 2.0
Milk	8.5 $\mu\text{c/l}$	1000 ml	8.5
Food	0.2 - 60 $\mu\text{c/kg}$	1200 gm	7

Totals

Min. - 17.0 - 17.6 $\mu\text{c/day}$

Max. - 18.3 - 60.3 $\mu\text{c/day}$

the contribution from air being insignificant and that from water being intermediate. In the case of untreated surface waters with a high strontium-90 content of 4.8 $\mu\text{C}/\text{l}$ and other intake levels as shown in Table III, the water intake would amount to 39 per cent of the total intake of strontium-90. In the case of cistern water supplies, the water contribution may exceed this percentage.

Taken alone, strontium-90 levels in surface water are not considered as adding any significant radiation exposure to humans. However, as pointed out above, the effect of strontium-90 in water must be evaluated in terms of the contribution of strontium-90, other radionuclides, and other radiation sources. This subject was discussed somewhat more extensively in a recent paper by the author and his associates (11).

With this background information, let us review the data on the removal of strontium-90 and other radionuclides from surface waters by conventional and modified water treatment methods. The bulk of this information is taken from papers previously published by the author (12,13,14).



General Considerations Relating to Water Decontamination

The removal of radioactive materials by water treatment process must be considered in terms of several recognized facts. These include: any treatment process transfers the radioactive materials from one phase to another--in this instance from the liquid to the solid phase; in this transfer of radioactive materials, there is no loss in the activity initially present except that lost through decay; in terms of mass, the quantities of radioactive materials with which we are concerned are very small as indicated in Table IV where permissible stable chemical compositions in the Public Health Service Drinking Water Standards (15) are compared with recommended permissible levels of corresponding radionuclides; and, since radioactive materials are chemical substances, processes that are effective for the removal of specific chemical substances are equally effective for the removal of their radioactive counterparts.

Furthermore, the degree of treatment to be provided must be geared to the maximum permissible concentration values recommended by the National Committee on Radiation Protection (16). Since these define, in the case of water or air, the currently recommended permissible levels of contamination, they may be used to calculate the degree of removal required to meet these levels when the nature and the amount of activity initially present in the water to be

Table IV. Quantitative Comparison of Chemical Characteristics U.S. Public Health Service Drinking Water Standards and Maximum Permissible Concentration of Radioisotopes in Water.

Chemical Constituent	Drinking Water Standards		Maximum Permissible Concentration		Radioactive Form
	ppm (mg/l)	µg/cc	µg/cc	µc/cc	
Grounds for Rejection (DWS)					
Lead (Pb)	0.1	1 x 10 ⁻¹			
Fluoride (F)	1.5	1.5 x 10 ⁰			
Arsenic (As)	0.05	5 x 10 ⁻²			
Selenium (Se)	0.05	5 x 10 ⁻²			
Chromium (Cr ⁺⁶)	0.05	5 x 10 ⁻²	5.2 x 10 ⁻⁶	0.5	Cr ⁵¹
Recommended Values (DWS)					
Copper (Cu)	3.0	3 x 10 ⁰	2.1 x 10 ⁻⁸	8 x 10 ⁻²	Cu ⁶⁴
Iron and			1.8 x 10 ⁻⁶	4 x 10 ⁻³	Fe ⁵⁵
Manganese			2.1 x 10 ⁻⁹	1 x 10 ⁻⁴	Fe ⁵⁹
(Fe + Mn)	0.3	3 x 10 ⁻¹	9.3 x 10 ⁻⁹	0.2	Mn ⁵⁶
Magnesium (Mg)	125	1.25x 10 ²			
Zinc (Zn)	15	1.5 x 10 ¹			
Chloride (Cl)	250	2.5 x 10 ²	8.9 x 10 ⁻²	2 x 10 ⁻³	Cl ³⁶
Sulfate (SO ₄)	250	0.83x 10 ²	1.2 x 10 ⁻⁷	5 x 10 ⁻³	S ³⁵
		(as sulfur)			
Phenolic compounds*					
(C ₆ H ₅ OH)	0.001	1.5 x 10 ⁻⁴ *	6.7 x 10 ⁻⁴	3 x 10 ⁻³	C ¹⁴

* Assuming that only one of the carbon atoms is radioactive C¹⁴.

treated are known. Conversely, if the efficiency of a particular process and the maximum permissible concentration for a given nuclide are known, the highest concentration of that component in waters used for public water supplies must be stipulated. Assume a water, for example, containing $10 \mu\text{c/ml}$ of promethium-147. The maximum permissible concentration for this radionuclide is $1 \mu\text{c/ml}$. This means that a decontamination factor of 10, equivalent to a 90 per cent removal, must be provided to reduce the level of this radionuclide to the recommended permissible concentration. In the case of strontium-89, with an MPC of $7 \times 10^{-5} \mu\text{c/ml}$, and a process that provides a 90 per cent removal of strontium, the highest concentration that may be present in the water prior to treatment is $7 \times 10^{-4} \mu\text{c/ml}$, if the recommended maximum permissible concentration is not to be exceeded. The difference in the initial concentrations of these two radionuclides--promethium-147 and strontium-89--varies by a factor of approximately 14,000. This is due entirely to the difference in *physiological characteristics* of these two nuclides.

Efficiency of Conventional Water Treatment Processes

Conventional water treatment processes include coagulation, settling, filtration, and disinfection. In addition auxiliary treatment, such as aeration, softening, ^{and} iron and manganese removal, may be employed.

Coagulation

Coagulation involves the formation of chemical flocs that

adsorb, entrap, or otherwise bring together suspended matter, particularly suspended matter that is colloidal. The addition of these coagulating chemicals results in the precipitation of some of the soluble constituents in the waste as metal hydroxides, generally hydroxides of aluminum or iron, since alum and iron salts are the most common coagulants.

With the exception of most cations of valence 3, 4, or 5, including the rare earths group, coagulation with settling has not been particularly effective for the removal of specific soluble radionuclides from water/^{as}shown in Table V. Removals in excess of 98 per cent have been reported for phosphorus-32 as the orthophosphate. The most extensively used radionuclide in medical therapy and research--iodine--being in the anion form (as the iodide) is not removed by coagulation with alum or iron. However, addition of small amounts of activated carbon, copper sulfate, or silver nitrate (17, 18) will markedly increase removals. Removals up to 96 per cent have been reported (18).

Coagulation will be helpful in the removal of radioactive material attached to, adsorbed on, or exchanged on the natural turbidity found in surface waters. Since coagulation will remove much of the turbidity, the activity associated with the particulate matter will also be removed.

Table V. Removal of Radioactive Materials by
Conventional Water Treatment Processes^a

Isotope	Chemical Coagulation and Settling	Sand Filtration	Soda-Ash Softening	Ion Exchange Resins		
				Cation	Anion	Mixed Bed
Ranges in Removal in Per Cent						
Cs ¹³⁷ -Ba ¹³⁷ (Cl)	0-37	10-70	< 50	99+	9	99+
Sr ⁸⁹ (Cl)	0-15	1-13	50-95	99+	5- 7	99+
Ba ¹⁴⁰ -La ¹⁴⁰ (Cl)	1-84	39-99	50-95	96-99	36-42	99+
Cd ¹¹⁵ (NO ₃)		60-99	50-99	98	0	99+
Sc ⁴⁶ (Cl)	62-99+	94-99	50-95	96-97	99	99
Y ⁹¹ (Cl)	1-99+	84-89	50-95	75-93	94-98	98-99
Zr ⁹⁵ -Nb ⁹⁵ (oxalate complex)	2-99	91-96	50-99+	58-75	96-99+	91-99+
P ³² (phosphate)	68-99+					99+
Cr ⁵¹ (Cl)	0-60					
Mo ⁹⁰ (MoO ₃)	0-60					
W ¹⁸⁵ (tungstate)	1-96	3-18	< 50	9-16	97-99+	99
Re ¹⁸⁶ (metal)	0-29					
I ¹³¹ (iodide)	0-96				99+	99+
Ru ¹⁰³ (Cl)	43-96					
Pr ¹⁴² (Pr ₂ O ₃)	83-99+					
Ce ¹⁴⁴ -Pr ¹⁴⁴ (Cl)	28-99+					99+
Pm ¹⁴⁷ (Cl)	4-99+					
Sm ¹⁵³ (Sm ₂ O ₃)	44-99+					

^a Variable chemical dose, coagulants, pH conditions, activity concentrations, and waters.

Sand Filtration

Except for removal by simple straining or sorbtion by biological life contained in the "Schmutzdecke", sand filters are not effective for the removal of radioactive materials. Their major function is to remove the radioactivity previously incorporated in floc particles that is not removed during settling. For example, scandium, yttrium, and zirconium-niobium, probably present in the colloidal state, were removed by mechanical straining, whereas other materials such as strontium, cesium, and possibly tungsten present in true solution, were not affected by passage through the sand filter.

Softening

Softening with lime and soda ash, under proper conditions, produced effective removals of strontium, barium, cadmium, yttrium, scandium, and zirconium-niobium. As shown in Table V, removals of 95 to 99 per cent or better are possible. For most satisfactory removal of strontium, increased amounts of both lime and soda ash were required (19). The mechanism of removal, in the case of strontium, is coprecipitation with calcium carbonate by the mechanism of crystal formation.

Lime soda ash softening is fairly effective in removing certain radionuclides from solution, if relatively high chemical dosages are employed. From the standpoint of emergency water

treatment, and with the use of high chemical dosages (Table VI) (19), the softening process could be adapted readily to the treatment of a waste containing radiostrontium. Other water treatment processes, with the exception of ion exchange, are relatively ineffective in removing this particular radionuclide, whereas under optimum conditions, softening can result in removals in excess of 99 per cent.

Ion Exchange

Another method of softening that has been practiced for some time in municipal and industrial water treatment is ion exchange. Removal of radioactive materials in solution is feasible by this process, and for most effective removals, mixed bed or cation and anion exchange beds in series are recommended. Results with various types of exchange materials are shown in Table V. Following ion exchange, it may be necessary to adjust the pH of the treated water. Data similar to that indicated under the cation exchange column were obtained with greensands, which are used extensively in municipal softening installations.

For adequate removals and economic operation, the waters being treated should be low in dissolved solids. Experience in the laboratory has shown that certain radioactive materials will continue to be removed (about 50 per cent removal) even though the column has been saturated with calcium and the hardness is no longer reduced.

Table VI. Results of Lime-Soda Ash Treatment
for Removal of Strontium

Treatment	Per Cent Removal of Activity
Stoichiometric amounts	75.0
20 ppm excess lime-soda ash	77.0
50 ppm excess lime-soda ash	80.1
100 ppm excess lime-soda ash	85.3
150 ppm excess lime-soda ash	97.3
200 ppm excess lime-soda ash	99.4
300 ppm excess lime-soda ash	99.7

Although the ion exchange process offers one of the most promising methods for the removal of radioactive contaminants, the initial and operating costs may prohibit widespread usage unless suitable regeneration techniques are developed.

Modified Processes for Water Decontamination

Several other methods have been studied for the removal of radioactive constituents from water. The most promising and perhaps most readily applicable to conventional water treatment plant facilities, phosphate coagulation (20), has effected removals up to 99.9 per cent as shown in Table VII. Also, relatively high removals of strontium are possible by this method, but these can be secured only under carefully controlled conditions of pH and of calcium hydroxide to tri-sodium phosphate ratio.

Studies utilizing an electrodialytic cell with permselective membranes (21) indicated the necessity of removing all colloidal radioelements prior to concentration of the soluble radioisotopes in the cell. Other methods of treatment include the addition of metal powders or clay materials. The results of these studies are reported in Table V. In general the highest removals with dusts were obtained with iron powder and exceeded 90 per cent, except for iodine, cesium, and a fission products mixture.

Table VII. Removal of Radioactive Materials by Modified Processes^a

Isotope	Phosphate Coagulation	Metallic Dusts	Clay Additions ^b
Ranges in Removal in Per Cent			
Cs ¹³⁷ -Ba ¹³⁷ (Cl)		9	98
Sr ⁸⁹ (Cl)	81-98		49-52
Ba ¹⁴⁰ -La ¹⁴⁰ (Cl)		66-95	85-98
Zn ⁶⁵ (Cl)	99+	98-99+	
Cd ¹¹⁵ (NO ₃)			64
Sc ⁴⁶ (Cl)			97
Y ⁹¹ (Cl)	99+	98	94
Zr ⁹⁵ -Nb ⁹⁵ (oxalate complex)	99+		98
P ³² (phosphate)		84-99+	78-82
Sb ¹²⁴ (Cl)	66		
W ¹⁸⁵ (tungstate)	11		49
I ¹³¹ (iodide)		23-46	9-20
Ru ¹⁰⁶ -Rh ¹⁰⁶		93-99+	
Co ⁶⁰ (Cl)		30-92	85-99+
Ce ¹⁴⁴ -Pr ¹⁴⁴ (Cl)	99+	99+	99+

^a Variable chemical quantities, levels of activity, and pH conditions.

^b 5,000 mg/l of clay added.

Clay materials have been added to waste solutions to permit the adsorption or exchange of soluble radioactive constituents in the water to the clays. The clays are then removed by coagulation or precipitation and settling. Although this method is feasible, large volumes of clay must be handled both initially and finally as a contaminated sludge for disposal.

Removal of Mixtures of Radionuclides

Up to this point, removal of specific radionuclides from water has been discussed. In the case of a fission product mixture or any mixture of radionuclides, the efficiency of removal is a function of the individual radionuclides comprising the mixture. Removals vary as indicated in Table VIII.

Removal of Fallout Materials

Rainfall is the major contribution of radioactive materials to the environment and some of this material finds its way into the stream as runoff as was indicated in one of the earlier sections of this paper. Since the material reaching the stream has been in contact with the natural environment for variable periods of time, the efficiencies obtained in treating waters containing these radionuclides are somewhat lower than those found with added radioactivity. The natural environment has been responsible for the removal of the easier-to-remove constituents from runoff. For example, at Albany,

Table VIII. Removal of Mixed Fission Products Isotopes

Mixture*	Treatment Process	Per Cent Removal
FPM - 1	Coagulation and settling plus clay	61 - 84
FPM - 2	Coagulation and settling	9 - 71
	Coagulation and settling plus clay	12 - 73
	Coagulation and settling plus clay	46
	Coagulation and settling plus filtration plus clay	70 - 73
FPM - 3	Coagulation and settling	46
FPM - 4	Coagulation and settling	89
	Mixed cation-anion exchange slurry	83 - 99
FPM - 5	Coagulation and settling	51 - 59
	Mixed cation-anion exchange slurry	38
	Metallic dust slurry	8 - 56
FPM - 6	Metallic dust slurry	77 - 92

*FPM - 1 Iodine dissolver solution.

FPM - 2 Synthetic mixture.

FPM - 3 Three year old fission products mixture.

FPM - 4 Iodine dissolver solution aged 30 days.

FPM - 5 Mixed fission product waste containing Cs¹³⁷-Ba¹³⁷ and Ru¹⁰⁶-Rh¹⁰⁶.

FPM - 6 Iodine dissolver solution aged 20 days.

New York, it was reported (22) that about 35 per cent of the gross activity due to fallout was removed in passing through the Albany water supply system and treatment plant which included coagulation, settling, and filtration. Similar studies reported by Thomas and co-workers (23, 24) for the Lawrence, Massachusetts, water supply showed an over-all removal of 80 per cent following coagulation, settling and filtration. Bell et al (24) reported lower removals at Cambridge and Lawrence, Massachusetts than those found by Straub (17, 25) for a simulated waste mixture containing increased concentrations of radioactive ruthenium, strontium, and iodine. Setter and Russell (27) reported results of laboratory jar tests of rain, cistern, and surface waters with chemicals and dosages used in conventional water treatment practice and concluded that all of the suspended gross beta activity and part of the soluble gross beta activity is removed. The longer the radioactive materials have been subjected to natural purification (adsorption on surfaces, sedimentation, or percolation), the more difficult it is to remove the remaining soluble activity by coagulation.

Summary and Conclusions

Unless related to the initial concentrations of the radioactive materials present, the percentage removal values cited in the various tables have little practical significance. It is only when these are considered in terms of the initial concentrations of

activity and the maximum permissible concentration, that one can be sure that the water is safe for human consumption. The maximum permissible concentration in water must be corrected for the presence of other radiation sources in the non water environment, specifically in the diet and other internal and external exposure.

Generally speaking, water treatment processes will be ineffective for reducing the activity in water to acceptable safe limits, unless the activity levels are very low, that is, in the 10^{-1} to 10^{-7} $\mu\text{c/ml}$ range, *depending on the nuclides present.*

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